Satellite Chartography of Atmospheric Methane and carbon monoxide from SCIAMACHY onboard ENVISAT

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Abstract
The UV/Vis/NIR spectrometer SCIAMACHY onboard the European ENVISAT satellite enables total column retrieval of atmospheric methane with high sensitivity to the lower troposphere. We apply an Iterative Maximum A Posteriori DOAS approach to derive vertical column densities of methane and carbon dioxide. Due to the low variability of CO_2, its total column retrievals are used as proxy for the probed atmospheric column and thereby allow us to convert methane column densities to column averaged mixing ratios. In addition, CO_2 abundances are modeled to account for possibly large seasonal variations in its total column. We discuss the retrieval algorithm and quantify possible impact factors on precision and accuracy (such as clouds and aerosols). On the global scale, the most pronounced CH_4 signal arises from source regions over India and South East Asia, broadly consistent with model simulations. SCIAMACHY retrievals, however, indicate higher CH_4 abundances over tropical Africa and tropical America, pointing to hitherto underestimated CH_4 emissions from tropical landmasses. First inverse modeling results using the methane retrievals will be shown to underline the enormous potential of SCIAMACHY with respect to global methane source inversions. Further, latest results of carbon monoxide retrievals revealing strongly enhanced abundances over the industrial regions in China and the seasonal patterns in biomass burning regions are shown.

Introduction & Data analysis
SCIAMACHY [1] onboard the European Space Agencies environmental research satellite ENVISAT is a grating spectrometer consisting of 8 channels measuring in the ultraviolet, visible and near infrared wavelength region (240nm–2380nm). The satellite operates in a near polar, sun-synchronous orbit at an altitude of 800km and a local equator crossing time of approximately 10:00 am. The typical ground pixel size of SCIAMACHY is 30km (along track) times 60km (across track), thus being a substantial improvement to the large footprint of the predecessor instrument GOME onboard ERS-2. SCIAMACHY is designed to measure sunlight that is either transmitted, reflected or scattered by the earth's atmosphere or surface. For this purpose it has 3 viewing geometries, nadir, limb and occultation. This work focuses only on Nadir spectra because they yield detailed information on the tropospheric CO and CH_4 abundances.
Methane (CH_4) is, after carbon dioxide, the second most important anthropogenic greenhouse gas, directly contributing 0.48 W m^{-2} to the total anthropogenic radiative forcing of 2.43 W m^{-2} by well-mixed greenhouse gases [2]. In addition, it exhibits an indirect effect of about 0.13 W m^{-2} through formation of other greenhouse gases, most notably tropospheric ozone and stratospheric water vapor [3]. Although the global annual source strength of methane (550 ± 50 Tg yr^{-1}) is comparatively well constrained, considerable uncertainties still exist in regard to the partitioning amongst sources and their spatial and temporal distribution. Recently, it was found [4] that plants can also directly emit methane in substantial amounts. This requires a repartitioning of other known sources such as wetland emissions. Satellites now offer the unique possibility of sensing methane globally, retrieving methane abundances in remote areas where ground based measurements might be complicated or even impossible due to infrastructural or political obstacles. However, owing to the long lifetime of methane, local gradients are small and thus the precision requirements challenging (1-2%). In [5] and [6], concurrent CO_2 retrievals have been introduced as proxy for the light path distribution, which largely reduced uncertainties due to partial cloud cover and aerosols. For the retrievals shown here, the IMAP-DOAS algorithm [7] is applied to SCIAMACHY spectra in channel 6.
Carbon monoxide (CO) exhibits absorption lines in the wavelength range of SCIAMACHY's channel 8. CO is one of the most important pollutants in the troposphere and although CO itself is not a greenhouse gas, it has an indirect effect on the climate as a sink for the OH radical, thus leading to longer lifetime of direct greenhouse gases such as CH_4 [1]. The main sources are presumed to be biomass burning, oxidation of hydrocarbons and methane as well as fossil fuel use [8]. Although the precision requirements are less strict than for methane (20% compared to 1-2%), the CO retrieval is complicated as the absorption lines are weak and overlapped by strong absorptions of methane and water vapour. Furthermore, channel 8 of SCIAMACHY poses problems due to an ice layer, high dark currents and low signal-to-noise ratios [9]. Despite these problems, considerable improvements in the CO and CH_4 retrievals have been achieved [10-14].
This paper focuses on recent results of methane and carbon monoxide retrievals. Details of the retrieval algorithm can be found in [5,6,7,13].

Results

As for methane, we focus our analysis on the year 2005 and two particular geographical regions, viz. Africa and China. Due to the location of Africa (nearly centered on the equator), we have good coverage with SCIAMACHY throughout the year. Further, wetlands and the newly discovered methane emissions from plants are supposed to exhibit a strong seasonal cycle in Africa. Hence, Africa is ideally suited for the observation of seasonal variations in methane abundances.

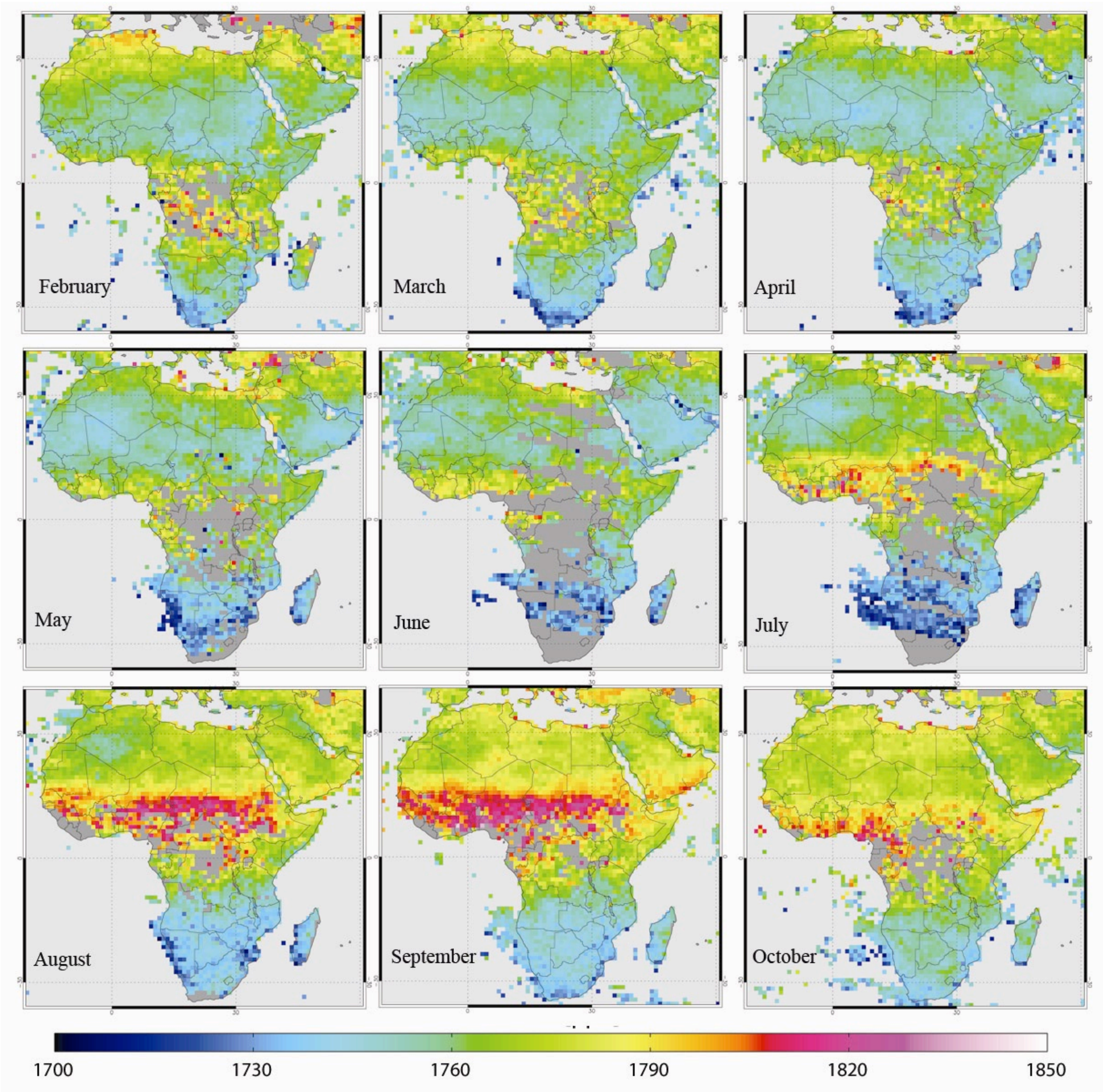

Fig. 1 Timeseries of column averaged volume mixing ratios of methane in 2005 (gridded on 1°x1°)

Fig. 1 shows monthly averages of methane column abundances over Africa from February through October 2005. It can be clearly seen that the regions with high methane abundances vary geographically in time. In February and March, the highest abundances are observed in the vicinity of the Congo basin. From July through October, however, high methane abundances occur in the savannas of sub-Saharan Africa. One has to bear in mind that some systematic biases in the SCIAMACHY retrievals can still exist but the data shown here reflect pronounced seasonal patterns in methane abundances over Africa. In [15], the SCIAMACHY dataset (2003-2004) has been applied in inverse simulations, revealing that tropical methane emissions are higher than previously estimated, thereby largely confirming [4] and [5].

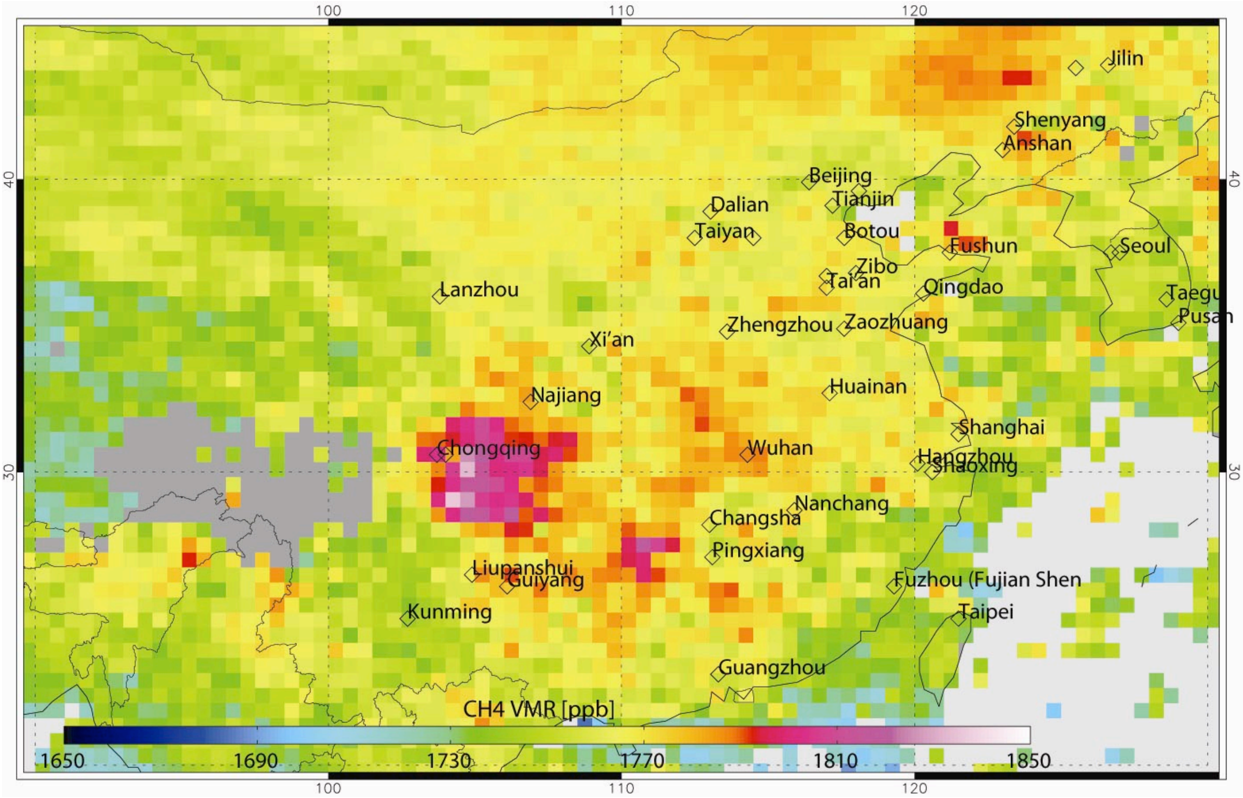

Fig. 2 Yearly average (2005) of methane abundances over China

Fig. 2 shows the yearly average of methane abundances over China for the year 2005. As in [6], the red basin (or Sichuan Basin) exhibits very high methane concentrations, on average the highest worldwide. [16] also identifies this area as one of the most important regions for methane emissions from rice paddies. The patterns of carbon monoxide abundances, however, look very differently as they are more strongly connected to industrial activity and air pollution.

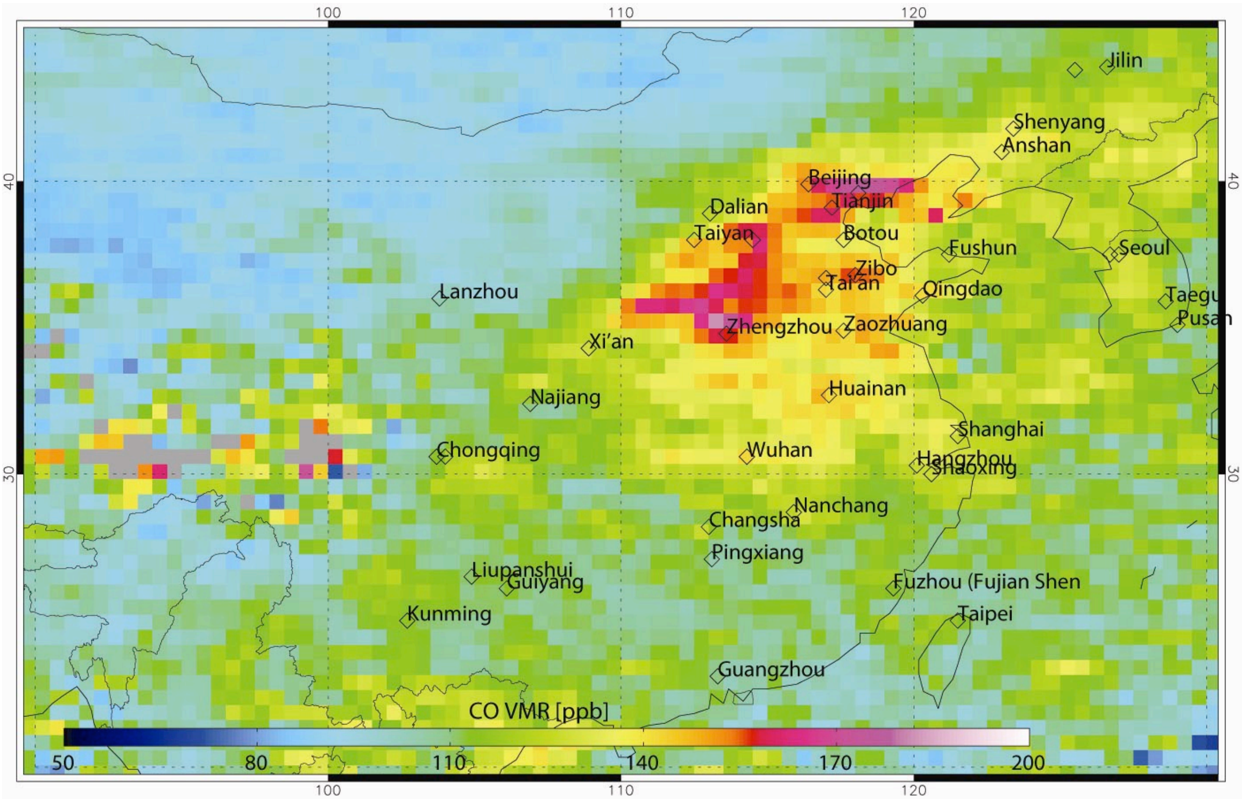

Fig. 3 Yearly average (2005) of carbon monoxide abundances over China

Fig. 3 shows the corresponding average carbon monoxide abundances over China. Strong local gradients are clearly identifiable. As for the retrievals of methane column averaged mixing ratios, the carbon monoxide mixing ratios were derived by rationing with the methane vertical column density in the same fitting window. Variations in methane are far smaller than the precision requirements for the CO retrieval and, furthermore, the rationing diminishes the bias induced by the growing ice layer on the SCIAMACHY detectors [17].
To further improve the carbon monoxide retrievals, information about the instrumental line shape (ILS) from spectral line source measurements onboard SCIAMACHY will be used to derive time-dependent ILS to be applied in the retrievals. This improvement is still in progress and not yet incorporated in the retrievals presented here. However, within the year 2005 no instrument heat up was performed and the transmission within channel 8 remained far more stable than in the preceding years.

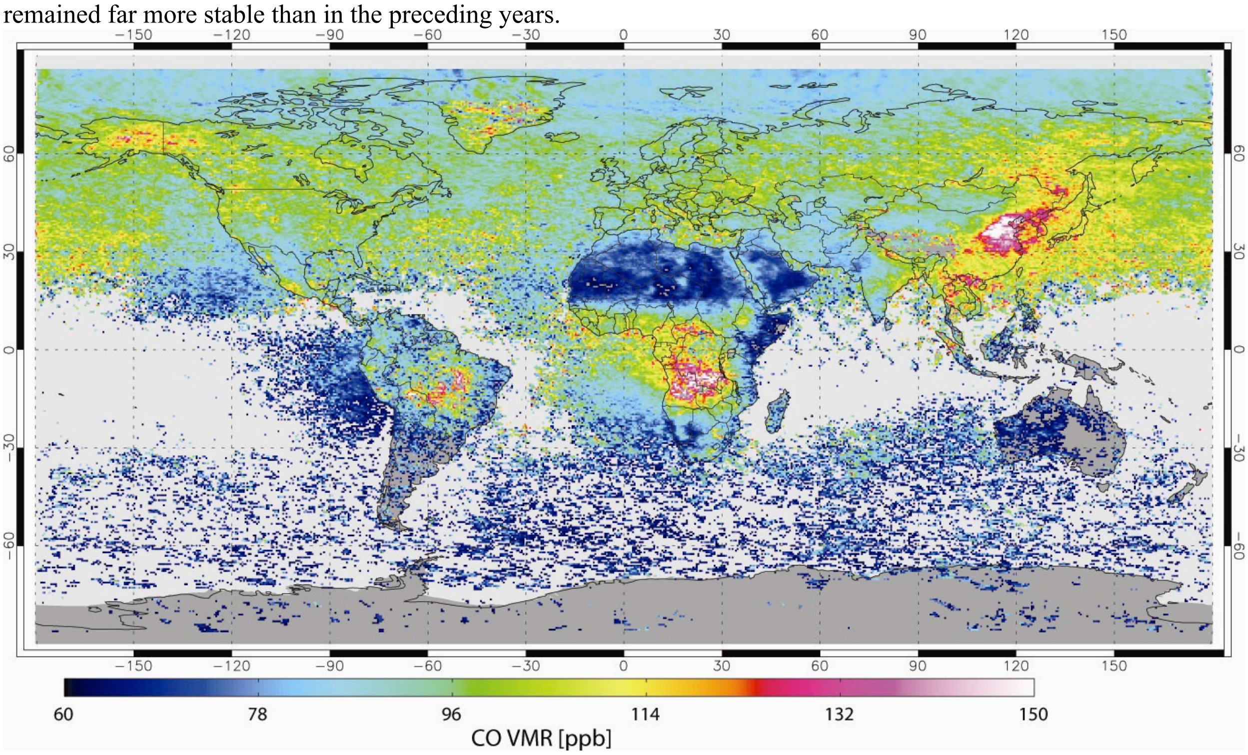

Fig. 4 2005 average of CO abundances

Fig. 4 shows a one year average (2005) of CO column averaged mixing ratios (using CH_4 as light path proxy). China and central Africa are the most striking regions with clearly enhanced abundances. Also South America and Alaska show enhancements. Retrievals over the Sahara seem to be slightly too low but it has to be mentioned that these retrievals are still preliminary and more improvements on the CO algorithm are planned. However, the seasonal variations over Africa (not shown here) can be clearly identified in CO abundances that are anti-correlated with methane abundances (e.g. in September we find high CH4 abundances in the savannah but high CO in the Congo basin whereas in February the opposite holds).

Conclusion & Discussion

The results of methane and carbon monoxide retrievals from SCIAMACHY as shown in this work for the year 2005 underline the potential of remotely sensed trace gas retrievals in the near infrared. Owing to the high sensitivity towards the ground, the near infrared spectral region is ideally suited to detect local enhancements in the abundances of the respective absorbers. Here we can only provide a glimpse at the data analysis and have to refer the reader to publications (esp. [7], [9-15]) that describe the methods and results in more detail. The application of SCIAMACHY retrievals in source inversion has already started [15] and promises vast improvements over inversions based on ground-based measurements solely.
Future work will focus on the characterization of possible systematic biases and correction schemes for time dependent slit functions in channel 8 of SCIAMACHY.

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